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✓ Spreadsheet
✓ DTS

MEMORANDUM FOR PRR (~~Contractor~~/In-House Publication)

FROM: PROI (TI) (STINFO) 20 May 1999

SUBJECT: Authorization for Release of Technical Information, Control Number: AFRL-PR-ED-TP-FY99-0105
Jay Levine, "Aerophysics"

International presentation ~~(Foreign Release)~~ Dist A

AEROPHYSICS

ESEP REVIEW MEETING
PARIS, FRANCE
1-3 JUNE

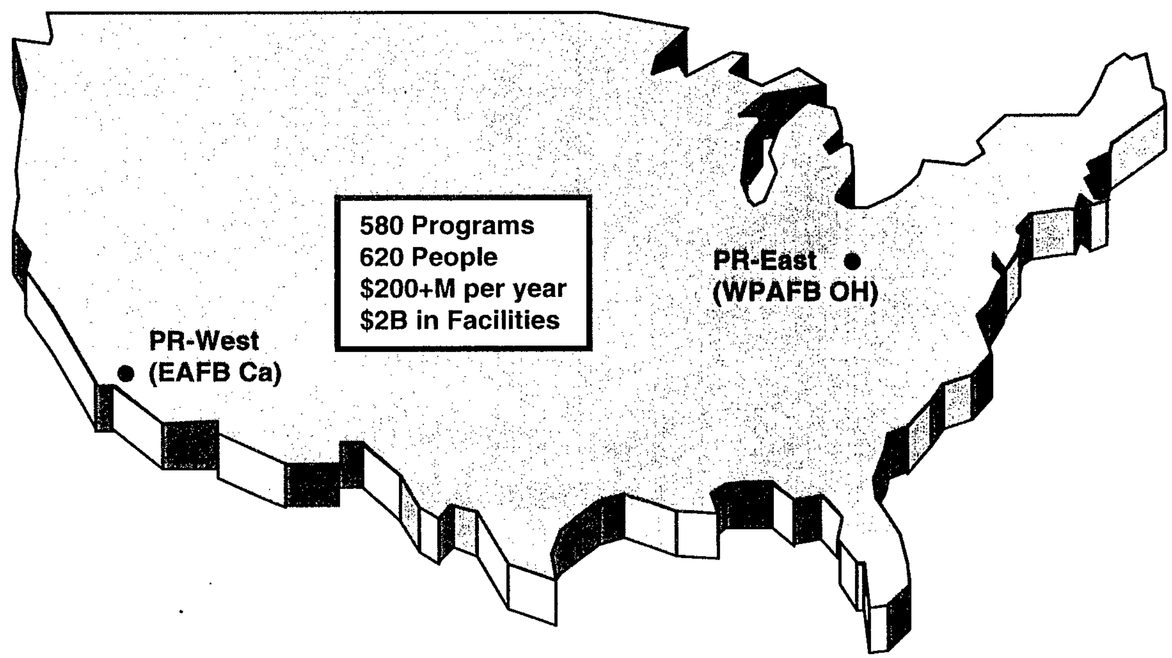
JAY LEVINE

Propulsion Sciences and Advanced Concepts Division
Air Force Research Laboratory
Edwards AFB, CA
(661)-275-6179
jay.levine@ple.af.mil

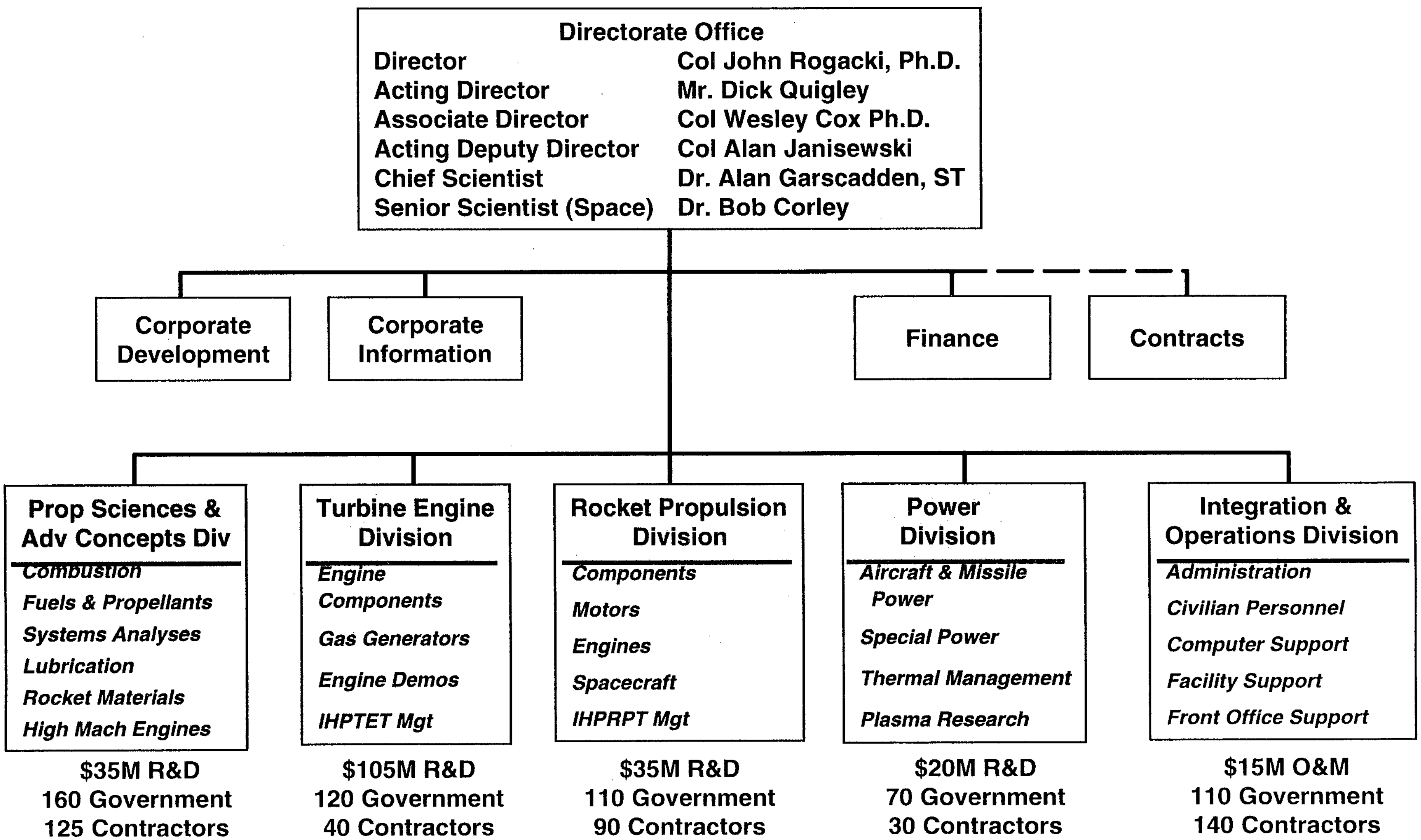
The *New* Propulsion Directorate (established 31 Oct 97)

One Stop Shopping For:

- Turbine Engines
- Ramjet Engines
- Rocket Engines
- Combined-Cycle Engines
- Satellite Propulsion
- Advanced Propulsion
- Fuels and Propellants
- Lubrication
- Aircraft Power
- “Special” Power
- System Analysis



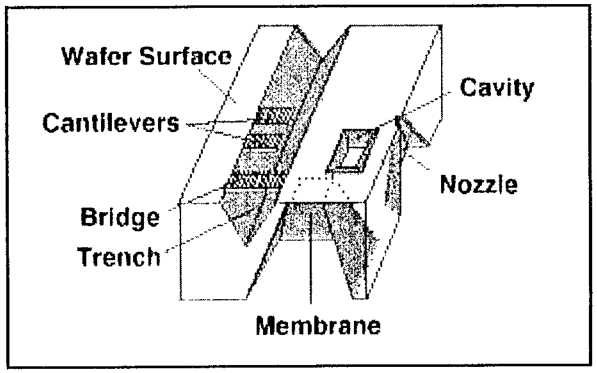
Propulsion Directorate



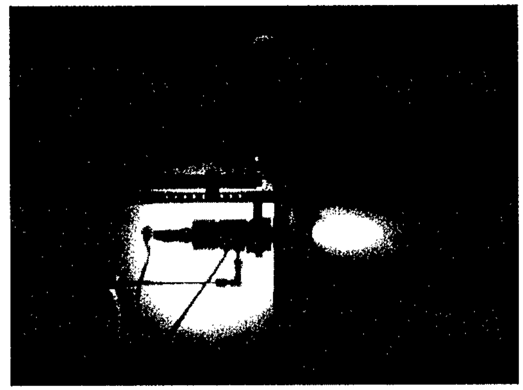
The Problem

- Nonequilibrium flows are not well characterized
  - Transport (mass, momentum, energy)
  - Relaxation (vibration, rotation, electronic)
  - Chemical Reactions (exchange, dissociation, recombination, decomposition, ionization)
  - Gas/Surface Interactions
- Nonequilibrium phenomena can dominate high altitude and micron scale flow physics
  - Observables
  - Spacecraft interactions - Contamination
  - Propulsion system performance

Micropropulsion Key Technologies

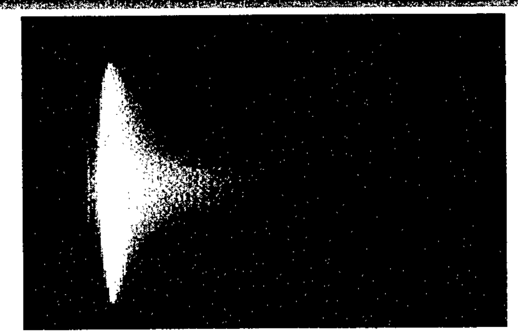


- Microelectromechanical Systems (MEMS) Fabrication
  - Propulsion System
  - Microvalves/Regulators
  - Heat Transfer Issues
  - Silicon Material Compatibility

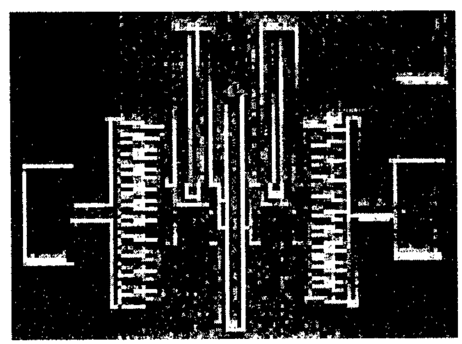


Thrust Stand Measurements for 1 to 100 μN Thrust Range

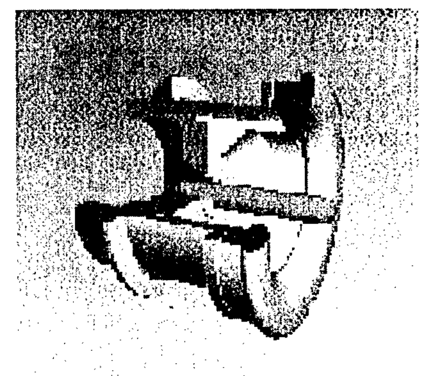
Spacecraft Contamination 3-D Modeling



- Plasma / Neutral Flow Characterization
  - Instrument Resolution

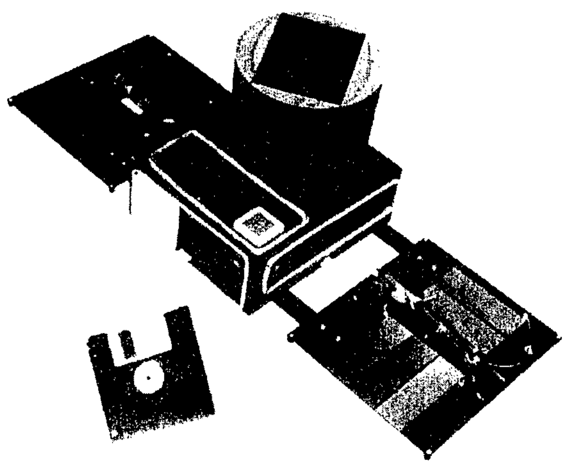


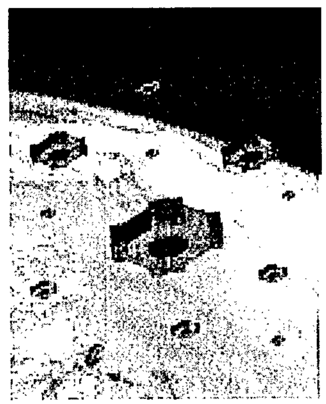
MEMS Flow Measurement Systems Embedded Low Power Integrated Microsensors (LPIM)



- Modeling of Complex Flows
  - DSMC
  - CFD
  - PIC
  - Heat Transfer

Micropropulsion Technology





PROBLEM

Propulsion is least developed spacecraft subsystem for micro-satellites

SOLUTION

Design, Develop and Characterize a wide range of micropropulsion concepts

PAYOFF

Low mass, low power and efficient microthrusters are an enabling technology for micro-satellite operations

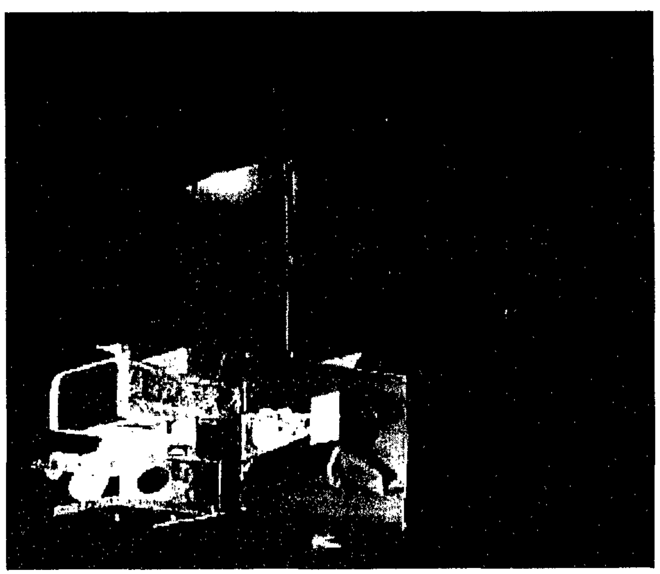
Trend toward reducing spacecraft size and mass for global, redundant (survivable) communications and surveillance systems

Integrated Approach

Basic research to understand phenomena which control microthruster performance
Transition research to development of range of unique microthruster concepts
Flight demonstration of most promising candidate designs

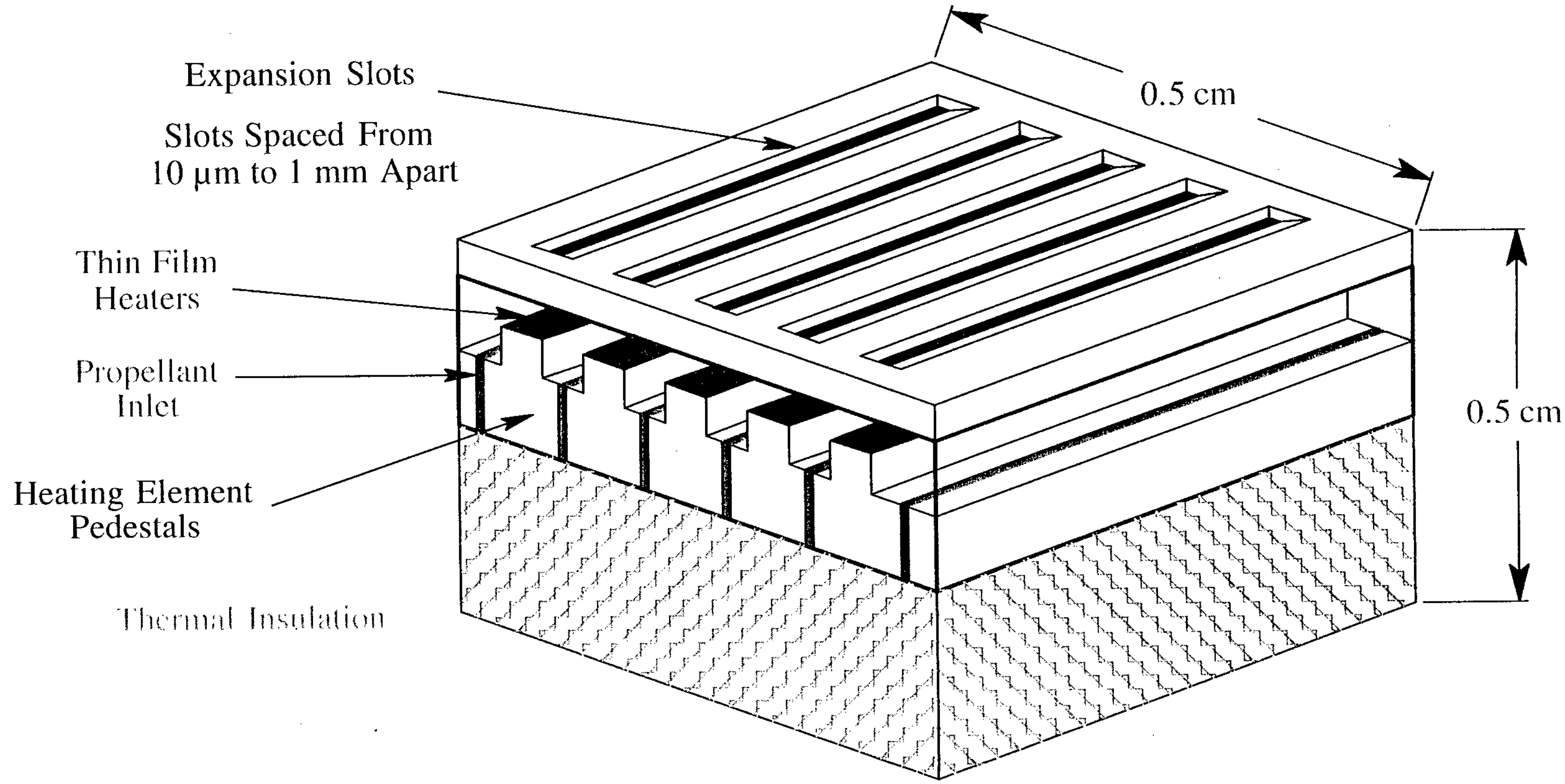
Spacecraft Contamination

- The current generation of spacecraft is typically sensitive to both molecular and particulate contamination
  - Thermal control coatings
  - High resolution and cryogenic optical sensors, solar panels



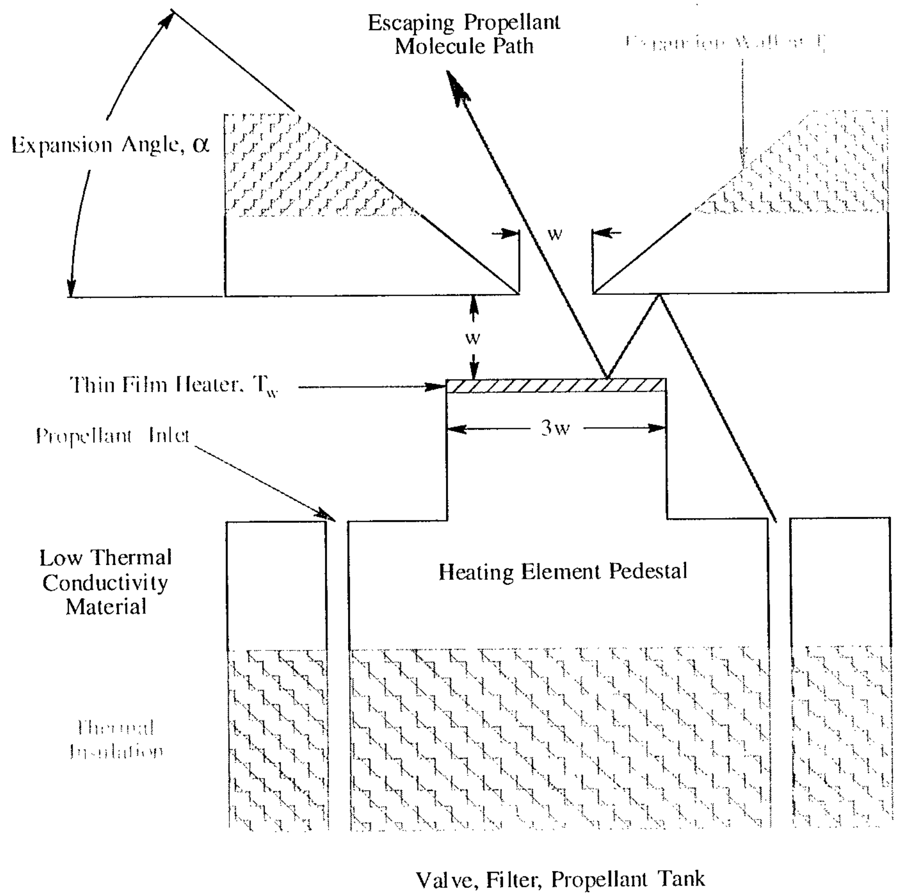
- For longer lifetime on orbit, it is essential that potential contamination sources be adequately identified and assessed to prevent performance degradation beyond acceptable levels
- Direct Simulation Monte Carlo (DSMC) codes are well suited for backflow contamination flowfield studies from thruster plumes and outgassing materials
  - Surface physics (surface/molecule interactions, degradation)
  - Continuum and gas dynamic effects (flowfield modeling)
- DSMC validation with experimental results both in the lab and on orbit (e.g. SBIRS, ESEX)
- Transition effort into the contamination potential of microthrusters on small spacecraft (individual systems and constellations)

FMMR Conceptual Design



FMMR Mounted Directly
to Valve, Filter and
Propellant Supply

Free Molecule Micro-Thruster: MEMS Fabrication



Slot Width: 100 to 1 μm
Stagnation Pressure: 20 to 2000 Pa
Stagnation Temperature: Up to 1200 K

Principle of Operation/Benefits

- Liquid or Gas Propellant (He,water, NH_3)
- Propellant Molecule Must Strike Heating Element Before Escaping Thruster (Inter-molecule collisions negligible)
- Rarefied Operating Condition Allows Small Thrust and I-bit With Reduced Valve Leakage
- Isp Independent of Operating Pressure
- MEMS Fabrication Techniques in Meso- to Micro- Scale Thruster

Performance and Characteristics

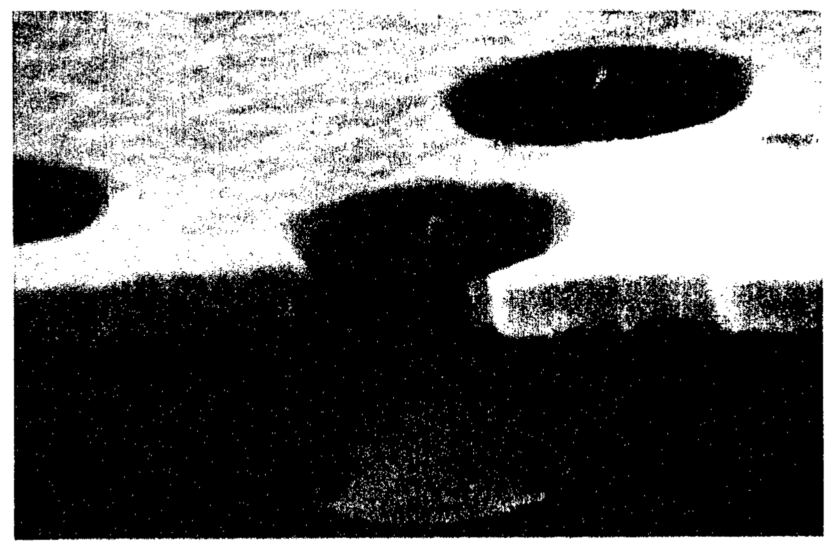
(Based on DSMC Numerical Results)

- Operating Temperature (T_w): 600K
- Slot Width: 100 μm
- Isp: 70 sec (NH_3), 45 sec (Ar)
- Thrust: 10 μN to 1 mN for 10 Slots
- Power: 1 to 3 Watts
- Efficiency " 50%

Field Emitter Arrays for Micro-Ion Thruster Concepts

- **MEMS Field Emitter Array Advantages**
  - **Small electrode spacing reduces potential (30-40 V/μm)**
  - **Relatively high electron current densities (100 - 1000 mA/cm^2)**

- Research Issues
  - Lifetime (Ion Induced Sputtering)
  - High Pressure Operation (1-10 mTorr)
  - Materials Research (nano-crystalline diamond, etc.)



The Problem

- Approximately 75% of engine development cost is spent on trial-and-error fixes of problems developed after design is complete.

The Objective

Eliminate more problems in the design phase before hardware is built.

The Approach

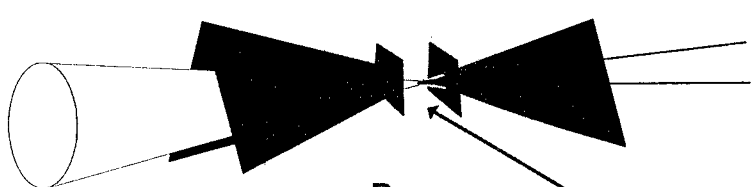
Develop design guidance at the *subscale* level, using *windowed, high pressure* test articles.

- *Directly* observe design impacts on relevant parameters

Dense Spray Diagnostics

(Best paper award, 1998 spray conference)

- Goal - Extend existing diagnostic techniques into the dense spray regime where $N > 10^5\ cc^{-1}$.
- The combination of a small probe volume and a flow splitter resulted in a dramatic improvement in PDPA volume flux measurements in a dense spray.



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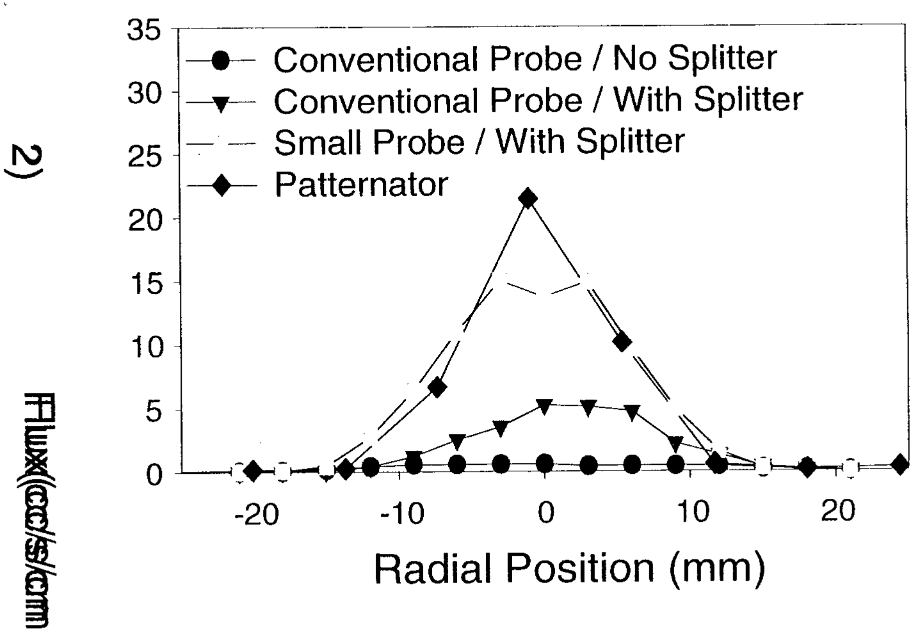
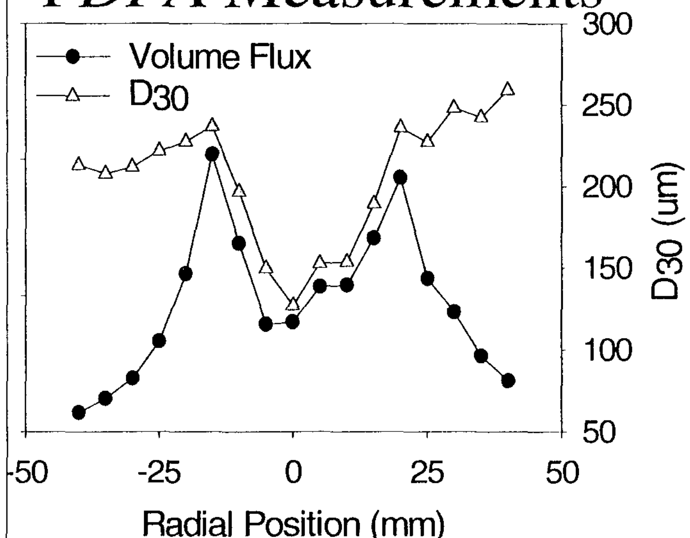


Liquid Engine Injector Testing

- A prototype gas-liquid coaxial injector was cold-flow tested. Measurements included droplet size, velocity and mass flux.
- 2-D laser sheet imaging of the spray indicated a solid cone spray, while PDPA measurements revealed a more hollow cone spray.
- Natural acoustic frequencies were also identified.

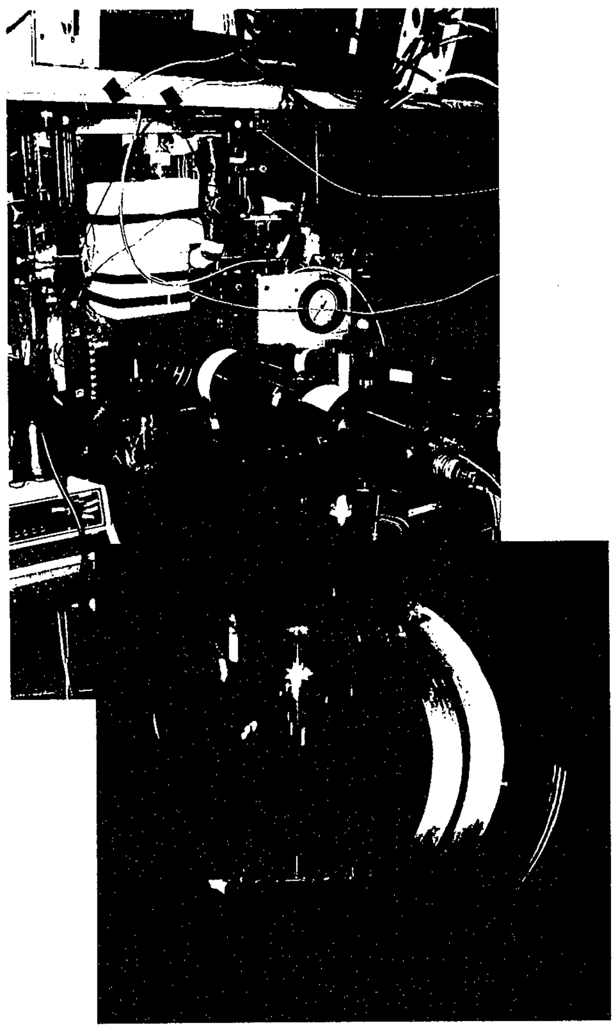
2-D Image

PDPA Measurements



High Pressure and Supercritical Combustion (6.1)

Supercritical pressure facility



OBJECTIVE

Determine the mechanisms which control the breakup, transport, mixing, and combustion of supercritical droplets, jets, and sprays.

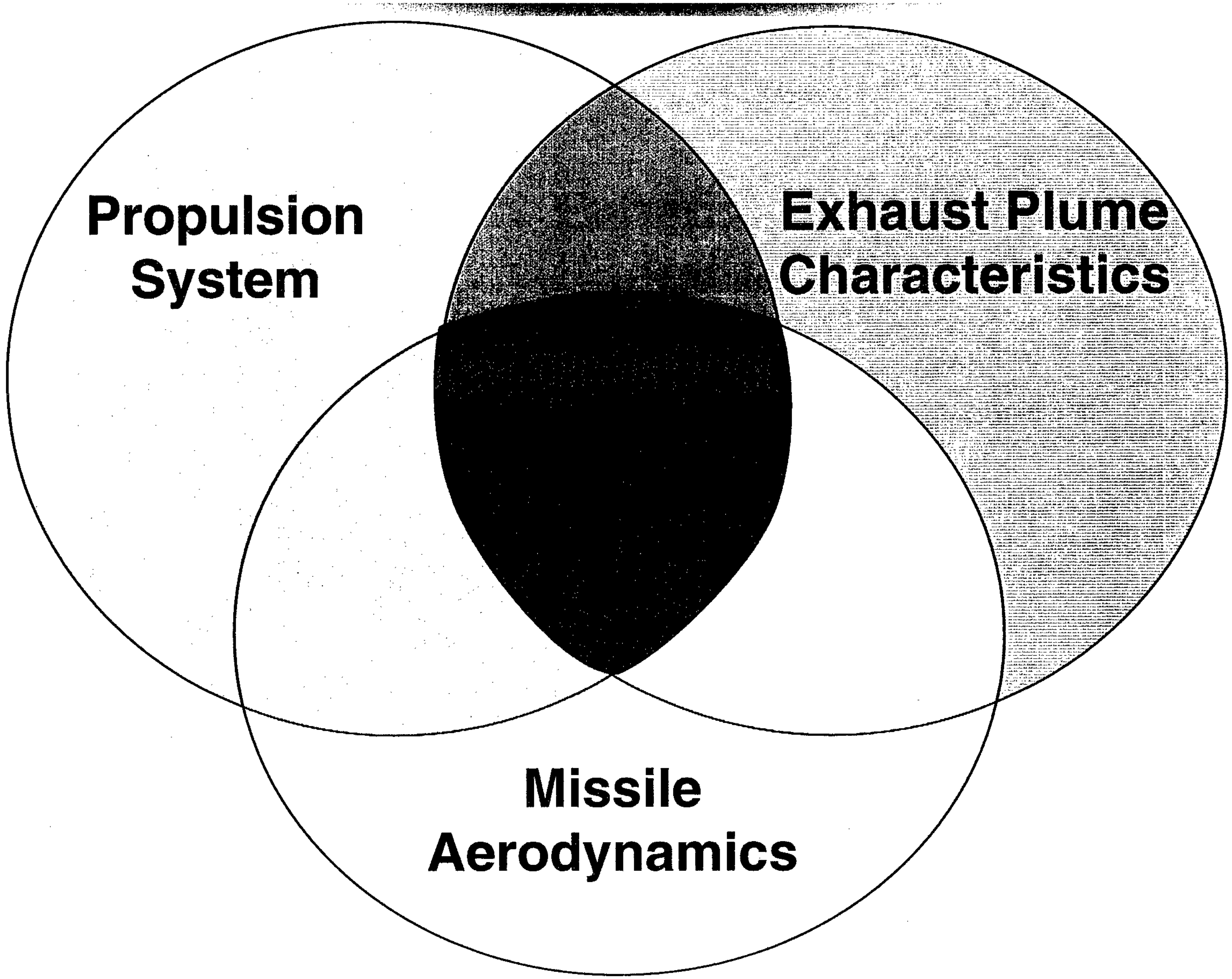
APPROACH

- Piezoelectic cryogenic jet and drop generator in chilled helium.
- Produce acoustic waves using metallic actuators, design resonant modes, focus acoustic waves.
- Reduce optical path lengths.
- Use spontaneous Raman scattering from a frequency doubled Nd-YAG laser.

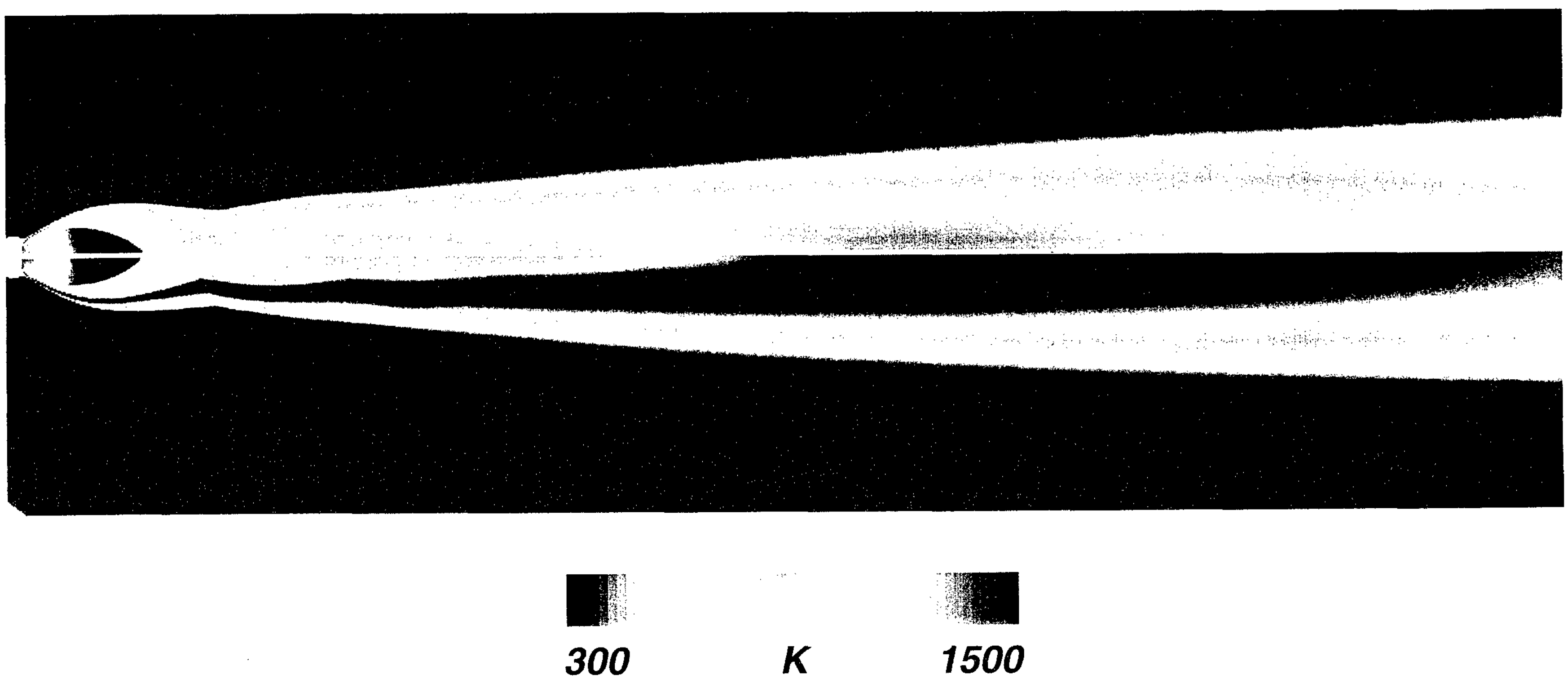
Introduction

- **Many System Considerations Enter Selection of a Thruster in Addition to the Isp of the Propellant**
- **The FMMR Is an Interesting Example of How a Novel Approach Can Be Used to Address Several General System Concerns**
  - Permits Very Small I-bits With Leisure Valve Actuation (100's of msec)
  - Maximum System Pressures of 0.02 Atm Solves Valve Leakage
  - Phase Change of Propellant (Ammonia, Water, etc.)
  - Smallest Dimension of Flow Passage Can Be Relatively Large Solving Nozzle Clogging Concerns (Single Point Failure)
  - Can Be Configured to Minimize Stagnation Chamber Heat Loss
  - Isp Relatively Constant Over Wide Range of Operating Conditions (Low and High Thrust Options From Same Thruster Without Performance Loss)

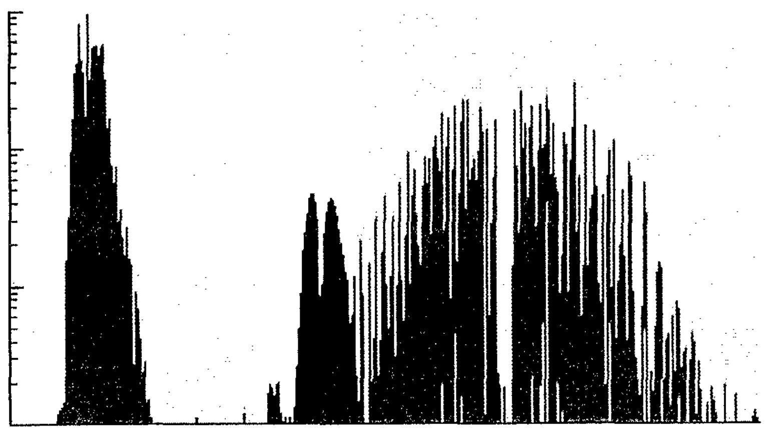
Origin of Target Signature



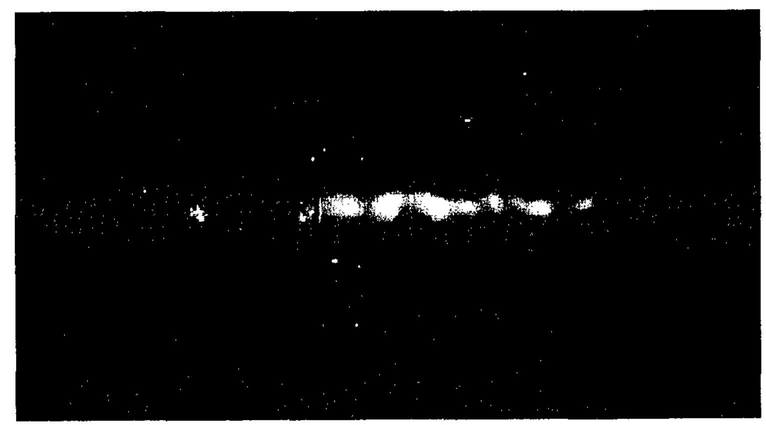
COMPARISON OF TEMPERATURE CONTOURS FOR LAMINAR AND PDF RATE MODELS AT 25 KM



Passive Signatures



Band-pass Selection

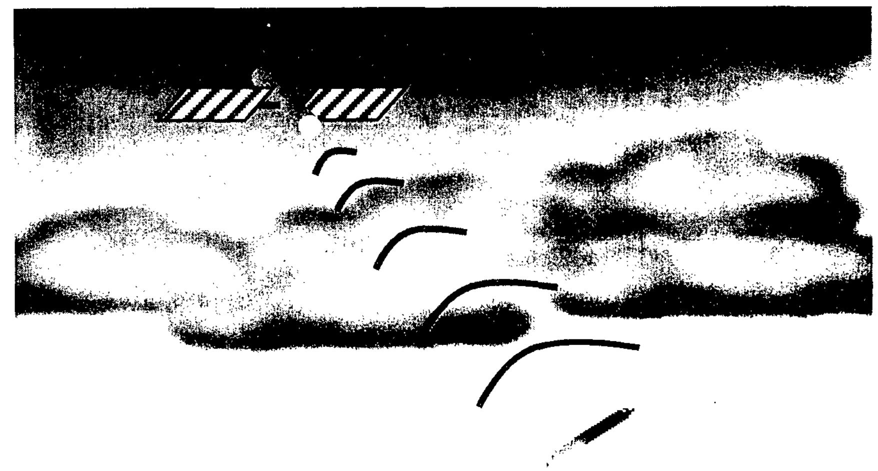


Detection, Acquisition Tracking, Cueing, Handover

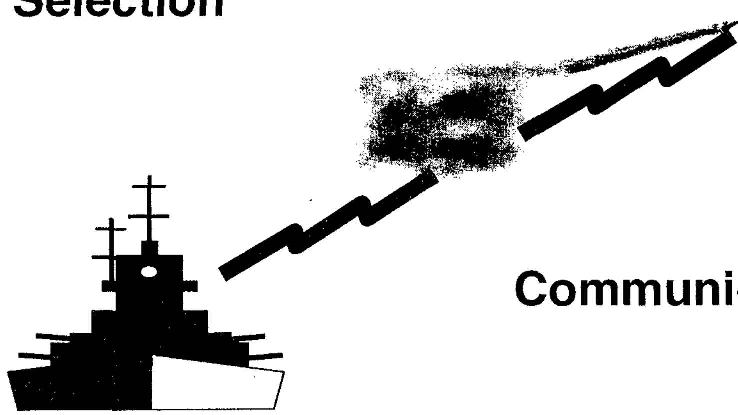
Emissions in the UV-LWIR (0.1-25 μm)

Active Signatures

Laser Backscatter and Aimpoint Selection



All Weather Detection, Tracking, Typing, and Cueing



Communications

BMDO Plume Phenomenology Program